Due Date: August 16, 2004

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE
BEFORE THE BOARD OF PATENT APPEALS AND INTERFERENCES

In re Application of:	
Inventors: Hugues Marchand et al.	Examiner: Matthew J. Song
Serial #: 09/922,122	Group Art Unit: 1765
Filed: August 3, 2001	Appeal No.: ________
Title: METHOD OF CONTROLLING STRESS IN GALLIUM NITRIDE FILMS DEPOSITED ON SUBSTRATES	

BRIEF OF APPELLANTS

Mail Stop APPEAL BRIEF - PATENTS
Commissioner for Patents
P.O. Box 1450
Alexandria, VA 22313-1450

Dear Sir:

In accordance with 37 CFR §1.192, Appellants' attorney hereby submits the Brief of Appellants, in triplicate, on appeal from the final rejection in the above-identified application, as set forth in the Office Action dated December 9, 2003.

Please charge $1005.00 to Deposit Account No. 50-0494 for the Request for Extension of Time for five (5) months. Also, please charge $165.00 to Deposit Account No. 50-0494 for the Appeal Brief filing fee as set forth under 37 C.F.R. 1.17(f). Please charge any additional fees or credit any overpayment to Deposit Account No. 50-0494.

I. REAL PARTY IN INTEREST

The real party in interest is The Regents of the University of California, the assignee of the present application.

II. RELATED APPEALS AND INTERFERENCES

There are no related appeals or interferences for the above-referenced patent application.

III. STATUS OF CLAIMS

Claims 1, 2, 4-9, 11-35, and 37-39 are pending in the application

Claims 3, 10 and 36 have been cancelled.

Claims 18-34 have been withdrawn from consideration.

Claims 1, 2, 4-9, 11-17, 35 and 37-39 stand rejected.

This is an appeal from the rejections of claims 1, 2, 4-9, 11-17, 35 and 37-39.

IV. STATUS OF AMENDMENTS

In an Amendment under 35 U.S.C. §1.116 submitted in response to the final Office Action, claim 36 was canceled. In an Advisory Action mailed December 9, 2003, it was indicated that the amendment would be entered for the purposes of appeal.

V. SUMMARY OF THE INVENTION

Appellants' invention as recited in independent claim 1 is directed to a semiconductor film (100), comprising a silicon (Si) substrate (104) and a graded gallium nitride (GaN) layer (102) deposited on the silicon substrate (104) having a varying composition of a substantially continuous grade from an initial composition (106) to a final composition (108). See e.g. FIG. 1 and page 7, line 15 to page 8, line 17 of the application as filed.

The invention addresses the problem of cracking which may be exhibited in gallium nitride films grown on silicon substrates according to other techniques. The cracking results from stresses (e.g., tensile stresses) generated in the gallium nitride films due to differences in thermal expansion rates between silicon and gallium nitride upon cooling from the growth temperature. The cracking limits, or prevents, use of such films in semiconductor device applications.

Compositionally-graded films of the present invention have favorable stress conditions which limit, or eliminate, the tendency of the films to crack. For example, the graded gallium nitride films may be placed in compressive stress. Embodiments of the invention that include a substantially continuous compositionally grade may be particularly effective in creating favorable

stress conditions which limit crack formation. By limiting cracking, high quality gallium nitride films may be produced. Other layers may be deposited on the compositionally-graded layer to form electronic and optoelectronic devices.

VI. ISSUES PRESENTED FOR REVIEW

1. Whether claim 39 fails to comply with the written description requirement under 35 U.S.C. §112, first paragraph.

2. Whether claims 1, 2, 4-9, 11-17, 35 and 37-39 are obvious under 35 U.S.C. §103(a) in view of Edmond et al., U.S. Patent No. 5,739,554 (Edmond) or Redwing et al., U.S. Patent No. 5,874,747 (Redwing) in view of Goetz et al., U.S. Patent No. 6,441,393 (Goetz).

VII. GROUPING OF CLAIMS

The rejected claims are grouped as indicated below:

A. Group I. For purposes of this Appeal only and for the rejection under 35 U.S.C. §112, first paragraph, claim 39 stands alone.

B. Group II. For purposes of this Appeal only and for the rejection under 35 U.S.C. §103(a) in view of Edmond or Redwing in view of Goetz, claims 1, 2, 4-9, 11-17, 35 and 37-39 stand or fall together.

Separate arguments for the patentability of each group are provided below.

VIII. ARGUMENTS

A. Non-Art Rejections – Rejection of Claim 39

In paragraph (4) of the Office Action, claim 39 was rejected under 35 U.S.C. §112, first paragraph, as failing to comply with the written description requirement. The Office Action asserts that the instant specification does not provide support for graded gallium nitride layers.

Appellants' attorney respectfully traverses this rejection for the reasons set out below.

First, contrary to the Office Action's assertion, the specification does provide support for a graded gallium nitride layers. For example, paragraph [0012] teaches:

> [0012] A typical semiconductor film comprises a substrate and a graded gallium nitride layer deposited on the substrate having a varying composition of a substantially continuous grade from an initial composition to a final composition formed from a supply of at least one precursor in a growth chamber without any interruption in the supply.

Moreover, the instant specification teaches such graded gallium nitride layers as they relate to stresses within the gallium nitride layers. For example, paragraphs [0025] and [0026] teach the following.

> [0025] The principal feature of the present invention is that the composition is varied continuously between the initial composition 106 and the final composition 108 without any interruption in precursor 110 supply. From ongoing materials studies it appears that the lack of interruption in the growth process prevents the layers with low aluminum content from dissipating the elastic energy associated with the lattice mismatch between material A and material B. Thus a larger amount of compressive strain is present in the layer structure than is found when using other methods. In many cases the compressive stress is large enough to counterbalance the tensile stress induced by the cool-down procedure such that the net stress in the epitaxial layers is compressive. Compressively-strained films do not crack, hence preserving the properties of any device that may have been subsequently deposited and processed.
>
> [0026] The grade 114 can be accomplished by a variety of methods known to those skilled in the art, such as …

Particularly with respect to claim 39, the specification teaches at paragraph [0008] that "GaN films exhibit cracking when the tensile stress exceeds approximately 400 MPa."

Accordingly, Appellants' attorney respectfully submits the subject matter of claim 39 is described in the specification in such a way as to reasonably convey to one skilled in the art that the inventor, at the time the application was filed, had possession of the claimed invention as required under §112, first paragraph.

B. Prior Art Rejections - Rejection of Claims 1, 2, 4-9, 11-17, 35 and 37-39

In paragraphs (5)-(6) of the Office Action, claims 1, 2, 4-9, 11-17, 35 and 37-39 were rejected under 35 U.S.C. §103(a) as being unpatentable over Edmond et al., U.S. Patent No. 5,739,554 (Edmond) or Redwing et al., U.S. Patent No. 5,874,747 (Redwing) in view of Goetz et al., U.S. Patent No. 6,441,393 (Goetz).

Appellants' attorney respectfully traverses these rejections for the reasons set out below.

As noted above, independent claim 1 is directed to a semiconductor film, comprising a silicon substrate and a graded gallium nitride layer deposited on the silicon substrate having a varying composition of a substantially continuous grade from an initial composition to a final composition. The cited references do not teach nor suggest these various elements of Appellants' independent claim. Particularly, the teachings of the cited references, alone or in combination, do not teach or suggest a graded gallium nitride layer deposited on a silicon substrate.

The Office Action essentially asserts that both Edmond and Redwing teach various graded gallium nitride layers that read on the graded gallium nitride layer of the present independent claim. The Office Action acknowledges that neither Edmond nor Redwing teach a silicon substrate, disclosing instead use of a silicon carbide (SiC) substrate. However, the Office Action notes that Goetz teaches, among other things, a substrate of sapphire, silicon carbide, silicon or gallium arsenide or gallium nitride and depositing a buffer layer thereon.. The Office Action then asserts that it would have been obvious to a person of ordinary skill in the art at the time of the invention to modify Edmond or Redwing with Goetz's substrate of silicon because substitution of known equivalents for the same purpose is held to be obvious.

Appellants' attorney respectfully disagrees.

1. Silicon and Silicon Carbide Are Not Equivalents

Appellants' attorney submits that silicon carbide and silicon are not equivalents in the context of the present invention and the cited references as asserted in the Office Action.

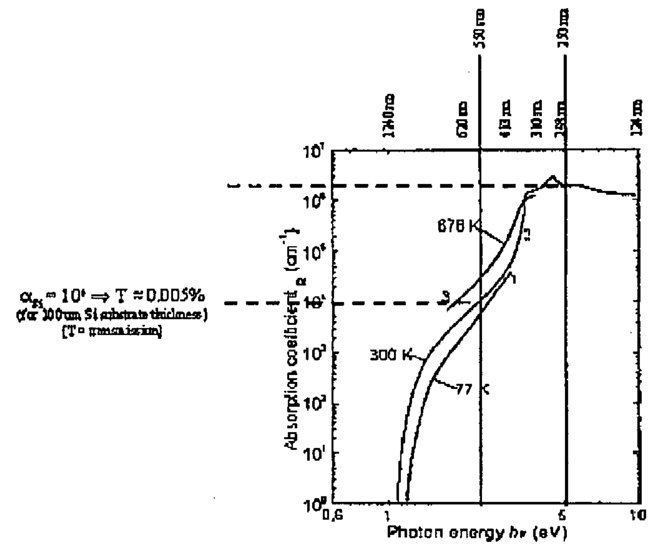
The lattice mismatch and thermal expansion mismatch between a substrate material and gallium nitride are important parameters when assessing the suitability of a substrate material for gallium nitride growth. Larger differences in lattice mismatch and thermal expansion mismatch between the substrate material and gallium nitride can lead to more severe cracking of the gallium nitride layers. As noted in the present specification, the lattice mismatch between the (001) plane of gallium nitride and the (111) plane of silicon is 17.6%, compared to 3.5% for silicon carbide; and, the thermal expansion mismatch of gallium nitride with silicon is +31%, compared to +17% for silicon carbide. (See, e.g., page 2, lines 28-33.) Because of these large differences, it is significantly more difficult to successfully grow gallium nitride on a silicon substrate than on a silicon carbide

substrate. Thus, silicon and silicon carbide are not equivalent substrate materials for gallium nitride growth.

In view of the large differences in lattice mismatch and thermal expansion mismatch between gallium nitride and silicon, there would have been no reasonable expectation of success when forming the claimed semiconductor film (including a graded gallium nitride layer on a silicon substrate) in view of the teachings in Redwing, Edmond and Goetz. Indeed, though silicon substrates were readily available when these references were filed, none of the references suggest the possibility of depositing such a graded gallium nitride layer on a silicon substrate.

Moreover, the transmission properties of silicon carbide and silicon are significantly different with respect to light emitted by gallium nitride. Gallium nitride emits light of characteristic wavelengths in the green-blue to ultraviolet region of the spectrum (See, e.g., Redwing, Col. 2, lines 37-45.) In light emitting devices (e.g., LED's), a large percentage of the light emitted by the gallium nitride layer(s) may pass through the substrate. (See, e.g., Redwing, Col. 11, lines 20-22.) Green-blue to ultraviolet light may be readily transmitted through silicon carbide substrates. (See, e.g., Redwing, Column 9, lines 54-66; FIGS. 2 and 3.) In contrast, light at these wavelengths is absorbed by silicon substrates, rather than being transmitted. Thus, as described further below, silicon and silicon carbide are not equivalent substrate materials in the context of light emitting gallium nitride device structures.

The following graph describes the absorption properties of silicon.



As noted above, silicon absorbs light having wavelengths in the green-blue to UV portion of the spectrum. The graph supports this position.

The graph includes curves at three different temperatures from two different references (curves 1 and 2 are from Sze, S. M., Physics of Semiconductor Devices, John Wiley and Sons, N.Y., 1981, while curve 3 is from Jellison, Jr., G. E. and F. A. Modine, Appl. Phys. Lett. 41, 2 (1982) pp. 180-182), though the room temperature curve (300 K) is most relevant. The wavelength scale was added at the top of the graph (which may be calculated directly from the photon energy). The graph shows that the absorption coefficient is very large (> 10^4 /cm) within the green-blue to UV portion of the spectrum (between about 250 nm and 550 nm, as shown by lines at those wavelengths). This means that silicon absorbs nearly all of the light having those wavelengths and transmits very little. From this data, the transmission of light at 550 nm (assuming a wafer thickness of 100 micron) is calculated to be 0.005% - obviously, a very small number.

Because of the above-noted differences, Appellants' attorney submits that silicon carbide and silicon are not equivalents in the context of substrate materials for gallium nitride growth and gallium nitride device structures as asserted in the Office Action. Moreover, there would have been no reasonable expectation of successfully forming the claimed semiconductor film (including a

graded gallium nitride layer formed on a silicon substrate) in view of the teachings in Redwing, Edmond and Goetz.

2. Redwing Teaches Away From A Silicon Substrate

As noted above, the Office Action acknowledges Redwing fails to teach a structure including a silicon substrate, but asserts that it would have been obvious to a person of ordinary skill in the art at the time of the invention to modify the Redwing structures by replacing the silicon carbide substrate with a silicon substrate as taught by Goetz.

Redwing is directed to gallium nitride-based light emitting devices. An object of Redwing's invention is to "provide bright green-blue to ultraviolet light emitting devices with high optical efficiency, …" (See, e.g., Redwing, Col. 6, lines 29-32.) The Redwing device structures include a gallium nitride layer (or layers) formed on a silicon carbide substrate with a graded buffer layer therebetween. Throughout the specification, Redwing repeatedly stresses the desirability and importance of employing a silicon carbide substrate. (See, e.g., Redwing, Col. 4, lines 10-51.) In particular, Redwing notes the importance of using a silicon carbide substrate in obtaining the desired light emission properties:

> The present invention is based on the discovery that by using **silicon carbide** of a selected prototype and growing Ga*N on that substrate in selected orientations, light emitting devices, e.g., a **green-blue to ultraviolet emitting laser or a green-blue to ultraviolet emitting diode,** of surprisingly high quantum efficiency and luminous efficiency may be fabricated. The luminescence efficiency, charger carrier mobilities and transmittance of light are improved.
>
> The substrate polytype and orientation are selected to optimize the performance of the light emitters. The properties that figure most strongly in this selection are crystal structure, charger carrier mobilities, and **transparency of the substrate to light of the wavelengths desirably emitted by the light emitters.** (Emphasis added) (Redwing, Col. 9, lines 54-67)

Redwing further stresses that "optical properties of the substrate are also important" because in light emitting devices "a great deal of light can come from out of the substrate." (See, e.g., Redwing, Col. 11, lines 13 and 20-21.)

If the Redwing devices were modified to include a silicon substrate as suggested in the Office Action, the devices would transmit less light in the green-blue to ultra-violet region. As noted above, a significant amount of light emitted from the Redwing devices is transmitted through the silicon carbide substrate. Because silicon absorbs light having wavelengths in the green-blue to ultraviolet region of the spectrum, such light would not be transmitted through a silicon substrate. Consequently, significantly less light would be emitted from the devices of Redwing if the devices were modified to include a silicon substrate. Thus, this modification would render the Redwing devices inferior (and, likely inoperable) for their intended purpose of emitting light in the green-blue to ultra-violet region. One of ordinary skill in the art, therefore, would not have been motivated to make this modification for at least this reason.

Accordingly, a prima facie case of obviousness has not been met with respect to the claim rejections in view of the combination of Redwing and Goetz.

3. Edmond Teaches Away From A Silicon Substrate

As noted above, the Office Action acknowledges Edmond fails to teach a structure including a silicon substrate, but asserts that it would have been obvious to a person of ordinary skill in the art at the time of the invention to modify the Edmond structures by replacing the silicon carbide substrate with a silicon substrate as taught by Goetz.

Edmond is directed to gallium nitride-based light emitting devices. The Edmond devices include a series of gallium nitride and aluminum gallium nitride layers formed on a silicon carbide substrate. In some embodiments, a buffer layer is formed on the silicon carbide substrate. Throughout the specification, Edmond emphasizes that the devices emit light in the blue portion of the visible spectrum. (See, e.g., Edmond, Col. 1, lines 6-9; generally, Col. 2, line 1 – Col. 4, line 2; Col. 5, lines 15-20; Col. 6, lines 30-34.) In the Edmond devices, some of the emitted light is transmitted through the substrate. In support of this point, Edmond notes that transparency is an important substrate characteristic in light emitting diodes (See, e.g., Edmond, Col. 3, lines 4-7.)

Similar to the Redwing devices discussed above, if the Edmond devices were modified to include a silicon substrate as suggested in the Office Action, the devices would transmit less light in the blue region. As noted above, some of the light emitted from the Edmond devices is transmitted through the silicon carbide substrate. Because silicon absorbs light having wavelengths in the blue

portion of the spectrum, such light would not be transmitted through a silicon substrate. Consequently, significantly less light would be emitted from the devices of Edmond if the devices were modified to include a silicon substrate. Thus, this modification would render the Edmond devices inferior (and, likely inoperable) for their intended purpose of emitting blue light. One of ordinary skill in the art, therefore, would not have been motivated to make this modification for at least this reason. Accordingly, a prima facie case of obviousness has not been met with respect to the claim rejections in view of the combination of Edmond and Goetz.

4. Goetz Teaches Away From Gallium Nitride On A Silicon Substrate

Finally, Goetz describes a semiconductor device having n-type device layers of III-V nitride having donor dopants such as germanium (Ge), silicon (Si), tin (Sn), and/or oxygen (O) and/or p-type device layers of III-V nitride having acceptor dopants such as magnesium (Mg), beryllium (Be), zinc (Zn), and/or cadmium (Cd), either simultaneously or in a doping superlattice, to engineer strain, improve conductivity, and provide longer wavelength light emission. Goetz teaches that the device may optionally include a substrate of sapphire, silicon carbide, silicon, gallium arsenide and gallium nitride. Importantly, Goetz specifically teaches a low temperature buffer layer 12 disposed between the substrate and a gallium nitride layer 13. (See, e.g., Goetz, FIG. 1 and Col. 6, lines 8-14.) Such teaching directs a skilled artisan away from a graded gallium nitride layer on a silicon substrate as presently claimed.

In response to Appellants' prior arguments regarding the buffer layer of Goetz, in paragraph (8) the Office Action has asserted that Goetz's teaching that the "various layers" may be smoothly graded over a finite thickness "would include grading the composition of the buffer layer." (See, e.g., Goetz, Col. 3, line 20 to col. 4, line 5.) Appellants' attorney respectfully disagree.

Goetz only indicates broadly what composition the "various layers" may comprise as they are discussed further in the specification. The examples and the details of the specification are necessary to determine which technique and composition form is possible for a particular layer. Throughout the specification, Goetz teaches low temperature buffer layers 12, 22, 52, indicating repeatedly that such a layer is used "due to difficulties in nucleation of the single crystalline III-V nitride layers on foreign substrates". In each case, Goetz notes only that a material such as GaN or AlN is used. (See, e.g., Goetz, Col. 3, lines 30-35, col. 4, lines 8-13 and lines 50-54.) Nowhere does

Goetz teach or suggest any of the buffer layers 12, 22, 52 as having a graded composition or define an example composition of a such a hypothetical graded buffer layer. In fact, the only layers Goetz describes as having graded compositions are the doped active layers (e.g., layers 13 and 14) with the grading being accomplished by varying dopant concentration. (See, e.g., Goetz, Col. 6, lines 15-37.) Appellants submit that Goetz can not be read to have such teaching applied to the buffer layers on a silicon substrate if not one example of such a graded buffer layer on a substrate is taught by Goetz.

Moreover, Goetz fails to disclose using any type of graded buffer layer formed on a silicon substrate as claimed.

5. Summary

As discussed above, Redwing and Edmond teach away from being modified to include a silicon substrate as taught by Goetz. Thus, one of ordinary skill in the art would not have been motivated to make such a modification. Furthermore, there would have been no reasonable expectation of success to make such a modification in view of the lattice mismatch and thermal expansion mismatch between gallium nitride and silicon. Accordingly, a prima facie case of obviousness has not been met with respect to claims 1, 2, 4-9, 11-17, 35 and 38-39 in view of the combination of Redwing and Goetz or the combination of Edmond and Goetz. Appellants' attorney respectfully requests reversal of these rejections.

6. Dependent Claims 2, 4-9, 11-17, 35, and 37-39

Further, dependent claims 2, 4-9, 11-17, 35, and 37-39 are submitted to be allowable over Edmond, Redwing and Goetz in the same manner, because they are dependent on claim 1 and thus contain all the limitations of the independent claim.

IX. CONCLUSION

In light of the foregoing arguments, Appellants' attorney respectfully submits that the cited references do not anticipate nor render obvious the claimed invention. More specifically, Appellants' claims recite novel physical features which patentably distinguish over any and all references under 35 U.S.C. §§ 102 and 103. As a result, a decision by the Board of Patent Appeals

and Interferences reversing the Examiner and directing allowance of the pending claims in the subject application is respectfully solicited.

Respectfully submitted,

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APPENDIX

1. A semiconductor film, comprising:

a silicon substrate; and

a graded gallium nitride layer deposited on the silicon substrate having a varying composition of a substantially continuous grade from an initial composition to a final composition.

2. The semiconductor film of claim 1, wherein the graded gallium nitride layer is deposited using metalorganic chemical vapor deposition (MOCVD).

3. (Cancelled)

4. The semiconductor film of claim 35, wherein the graded gallium nitride layer is deposited by changing a vapor pressure of the supply of at least one precursor in a growth chamber for the graded gallium nitride layer.

5. The semiconductor film of claim 35, wherein the precursor is gallium, aluminum or nitrogen.

6. The semiconductor film of claim 35, wherein the graded gallium nitride layer is deposited by changing a parameter of the growth chamber for the graded gallium nitride layer.

7. The semiconductor film of claim 6, wherein the parameter of the growth chamber is a total pressure, a temperature of the substrate, a total flow, a rate of substrate rotation or a reactor wall temperature.

8. The semiconductor film of claim 35, wherein the graded gallium nitride layer is deposited by changing the geometry of the growth chamber for the graded gallium nitride layer.

9. The semiconductor film of claim 8, wherein changing the geometry of the growth chamber comprises moving the silicon substrate relative to injectors of the growth chamber.

10. (Cancelled)

11. The semiconductor film of claim 1, wherein the initial composition comprises substantially at least a 20% aluminum composition.

12. The semiconductor film of claim 1, wherein the initial composition is aluminum nitride or an aluminum content aluminum gallium nitride where the aluminum content comprises substantially at least 20%.

13. The semiconductor film of claim 1, wherein the final composition comprises substantially less than a 20% aluminum composition.

14. The semiconductor film of claim 1, wherein the final composition is gallium nitride or an aluminum content aluminum gallium nitride where the aluminum content comprises substantially less than 20%.

15. The semiconductor film of claim 1, further comprising at least one additional layer disposed on the graded gallium nitride layer.

16. The semiconductor film of claim 35, wherein at least one other element is introduced into the growth chamber for the graded gallium nitride layer causing no abrupt variations in the varying composition of the graded gallium nitride layer.

17. The semiconductor film of claim 16, wherein the other element is silicon, indium or arsenic.

18-34. (Withdrawn)

35. The semiconductor film of claim 1, wherein the graded gallium nitride layer is formed from a supply of at least one precursor in a growth chamber without any interruption in the supply.

36. (Cancelled)

37. The semiconductor film of claim 1, wherein the graded gallium nitride layer has a net compressive stress.

38. The semiconductor film of claim 1, wherein the graded gallium nitride layer has a net stress below a stress required for crack generation in the graded gallium nitride layer.

39. The semiconductor film of claim 38, wherein the stress required for crack generation is less than about 400 MPa in tension.